Master 2 at ULIEGE

“Offshore Structures & Digital Twin”

<u>The 60 credits at ULIEGE are composed of:</u>

- 30 ECTS lectures during the 3rd semester
- 30 ECTS Master Thesis (integrated with the Internship) during the 4th semester

The Master Thesis can be undertaken in ULIEGE or in other labs and companies in Belgium or abroad.

SEMESTER 3: Lectures (30 credits)

EMSHIP	Mandatory lectures (15 credits)	CREDITS
M2-ULIEGE-1	Technology of Offshore Wind Structures	5
M2- ULIEGE-2	Structural health monitoring for offshore structures	5
M2- ULIEGE-3	Digital Twins and Operations of Marine Structures	5
	Elective lectures (15 credits)	
M2- ULIEGE-4	Reliability and stochastic modelling	5
M2- ULIEGE-5	Structural and multi-disciplinary optimization	5
M2- ULIEGE-6	Mechanics of Composites (of Marine Structures)	5
M2- ULIEGE-7	Fracture Mechanics, Damage & Fatigue (*)	5
M2- ULIEGE-8	Vibration testing and exp. modal analysis (**)	5

- (*) (**) ULIEGE Prerequisites. If a prerequisite is not acquired when the student arrives at ULIEGE, this lecture will be included in his/her program
- (*) Finite Element Method (5 cr) , instead of “Fracture Mechanics, Damage & Fatigue”
- (**) Theory of vibrations (5 cr), instead of “Vibration testing and experimental modal analysis”

SEMESTER 4: MASTER THESIS AND INTERNSHIP (30 credits)

Course code	Course title	ECTS credits
M2-ULIEGE-7	Master Thesis	20
M2-ULIEGE-8	Internship in a Company or Laboratory	10

The Master thesis is formally under the responsibility of ULIEGE, as ULIEGE delivers his Master specialized in "Offshore Structures and Digital Twin" (2nd year Master) at the end of the program.

See info on **MASTER PROGRAM IN MECHANICAL ENGINEERING (EMSHIP),**
https://www.programmes.ULIEGE.be/cocoon/20222023/en/programmes/A2UMEC01_C.html

Students can perform their Master thesis in ULIEGE, in a university laboratory, in a private company, in a research centre in Spain or abroad.

Students can also perform their Master thesis in one of the partners of the EMSHIP consortium.

In all cases, the topic of the Master thesis must be in relation to "Ships and Offshore Structures, Digital Twin" and has to be validated by ULIEGE.

The duration of the Master Thesis is five months. Students must write a Master Thesis report and defend their work at the end of their Master Thesis; this defence is organized by ULIEGE.

ULIEGE Teaching team

The ULIEGE academic board involved in the EMSHIP program will be composed initially by:

- Ph. Rigo (Prof.) ULIEGE
- P.G. Morato (Dr., Lecturer) ULIEGE
- P. Duysinx (Prof) ULIEGE
- Greg Dimitriadis (Prof) ULIEGE
- P Dewallef (Prof) ULIEGE
- A. Hage, (Lecturer, retired) external

EMSHIP LECTURES - ULIEGE

List of Lectures - Master MECA are available on:

https://www.programmes.ULIEGE.be/cocoon/20222023/en/programmes/A2UMEC01_C.html

EMSHIP Mandatory Lectures are:

Technology of Offshore Wind Structures (5 cr)
Structural health monitoring for offshore structures (5cr)
Digital Twins and Operations of Marine Structures (5 cr)

EMSHIP Elective lectures are:

Reliability and stochastic modeling (5cr)
Structural and multi-disciplinary optimization (5 cr)
Mechanics of Composites (of Marine Structures) (5 Cr)
Fracture Mechanics, Damage & Fatigue (5 Cr)
Vibration testing and exp. modal analysis (5 Cr)

Title: **Technology of Offshore Wind Structures** **5 credits** Ref: EMSHIP_M2-ULIEGE-1 **Prof:** ***P.Dewallef, P. Rigo, Lucas Marquez*** Teaching Period: sem. 3	
Link: *To be defined.*	
Course contents Design of fixed and offshore OWT, including - the comprehension of the structural design principles, - integrated design, - material technologies, - site assessment, - dynamics of floating offshore structures, - mooring and analysis. - Knowledge about technologies on fixed and floating support structures.	
Learning outcomes *Basic knowledges about* technologies on fixed and floating support structures.	
Prerequisites .	

Title: **Structural health monitoring for offshore structures** **5 credits**

Ref: EMSHIP_M2-ULIEGE-1

Prof: ***to be defined*** Teaching Period: sem. 3

Link: *To be defined.*

Course contents

- Introduction and motivation.
- Operational evaluation. Forward and inverse analysis.
- Data acquisition. Sensor technologies.
- Signal processing, data normalization, and feature extraction.
- Model-based (vibration) structural health monitoring (SHM).
- System identification. Experimental modal analysis. Operational modal analysis.
- Data-based SHM: supervised and unsupervised learning methods.
- Polymorphic uncertainties (aleatory and epistemic).
- Robust performance indicators.
- Introduction to asset management.
- Student class projects. Application towards offshore wind structures.

Learning outcomes

During the course, the students will learn to systematically conceive and maintain structural health monitoring systems with the aim of controlling the functional and operational behaviour of offshore structures.

Prerequisites

Basic knowledge in probabilistic methods and structural mechanics.

Title: **Digital Twins and Operations for Marine Structures** **5 credits**

Ref: EMSHIP_M2-ULIEGE-1

Prof: *Ph Rigo; Lucas MArquez* Teaching Period: sem. 3

Link: *To be defined.*

Course contents

- Introduction and motivation. What is a digital twin?
- Life-cycle optimization. Design, manufacturing, operation, and decommissioning phases.
- Deterioration processes. Fatigue and corrosion mechanisms.
- Physics-based modelling. Multi-physics simulators (e.g., OpenFast).
- Data-based modelling. Introduction to machine learning (statistical regression, neural networks). Surrogate models.
- Structural design driven by physics-based machine learning.
- Maintenance approaches. Calendar-based, condition-based monitoring, preventive.
- Uncertainty quantification and Bayesian (model) updating. Inspection and monitoring models.
- Utility theory. Introduction to quantitative risk analysis. State updating versus model updating.
- Decision-making optimization methods. Markov decision processes and deep reinforcement learning.
- Student class projects. Application towards offshore wind structures.

Learning outcomes

During the course, the students will learn to identify optimal life-cycle strategies for offshore structures through digital twin generation and model updating.

Prerequisites

Basic knowledge in probabilistic methods and structural mechanics.

Title: **Uncertainty quantification and stochastic modelling**	**5 credits**
Ref: MECA0010-1	
Prof: Maarten Arnst	Teaching Period: sem. 3

Link: https://www.programmes.ULIEGE.be/cocoon/20222023/en/cours/MECA0010-1.html

Course contents

Engineering structures and systems are rarely perfectly known, may present defects, and are often subjected to loadings that can be random or difficult to predict, thus making their design, fabrication, operation, reliability, maintenance, and simulation uncertain. This course aims at familiarizing the students with probabilistic methods that can be used to account for uncertainties in engineering analyses and to ascertain the accuracy of simulation predictions.

After a brief review of the basic concepts from the probability theory and from statistics, the course will be divided into two parts. The first part is dedicated to stochastic modeling in science and engineering. Some emphasis will be placed on the role that stochastic modeling can play in so-called inverse problems, in which model parameters must be estimated from data. Among other illustrations, we will consider applications in the biomedical sciences and engineering, including stochastic modeling of infectious disease spread and epidemiology.

The second part is dedicated to probabilistic methods for the quantification of uncertainties in engineering analysis. After presenting the most widespread and most used probabilistic methods (ISO98 Guide), attention will be turned towards more leading-edge probabilistic methods that are still the subject of ongoing scientific research (Monte Carlo methods, surrogate modeling, polynomial chaos methods, sensitivity analysis).

Learning outcomes

- Understanding of the uncertainties that may affect the behavior, evolution, and simulation of structures and systems in mechanics and physics.
- Ability to apply probabilistic methods for the quantification of uncertainties.
- Ability to find and read papers from the scientific literature.
- Ability to communicate effectively in written reports and oral presentations.

Prerequisites

Students ideally have a background in probability theory, statistics, and stochastic processes. The required background material will be recalled in class as needed.

Title: **Structural and multi-disciplinary optimization** **5 credits**

Ref: MECA0027-1
Prof: Pierre Duysinx and Patricia Tossings Teaching Period: sem. 3

Link: https://www.programmes.ULIEGE.be/cocoon/20222023/en/cours/MECA0027-1.html

Course contents
Part I - Introduction to numercial methods to solve optimization problems:

- Fundamentals of Mathematical Programming (including KKT conditions)
- Unconstrained Optimization: Gradient Methods (including conjugate directions)
- Line Search Techniques
- Unconstrained Optimization: Newton, Newton-like and Quasi-Newton Methods
- Quasi-Unconstrained Optimization
- General Constrained Optimization: Dual Methods
- General Constrained Optimization: Transformation Methods (including SLP and SQP)

Part II - Application to structural and multidisciplinary optimization:

- Fundamental Concepts in Structural and Multidisciplinary Optimization
- Finite Element and Optimization
- Optimality Criteria (OC)
- Sensitivity Analysis for Finite Element Model
- Structural approximations
- Solving efficiently CONLIN and MMA using dual sovers
- Introduction to shape optimization
- Introduction to topology optimization

Learning outcomes

At the end of the course the participants will be familiar with the fundamental optimization concepts applied to automatic design process.

The students will be able:

- to understand the principles of algorithms and optimization methods,
- to develop solution schemes to simple engineering optimization problems related to design or parameter identification (including the development of computer programs written in MATLAB language),
- to choose efficient formulations and optimization algorithms to solve their own problems using commercial tools,
- to get started with using an industrial optimization software tool (NX-TOPOL).

Prerequisites

- Mathematical analysis of real functions
- Matrix algebra
- Matlab programming (basic level)
- Finite Element Method
- Mechanical Vibrations: eigenfrequencies, eigenmodes, mechanical systems with N-degrees of freedom

Title: **Mechanics of Composites for Marine Structures** **5 credits**

Ref: EMSHIP M2-ULIEGE-1
Prof: *To be confirmed in 2024* Teaching Period: sem. 3

Link: *To be defined in 2024.*

Course contents

The course introduces different aspects of fiber-reinforced plastic materials for marine structures.

Overall description: constituents, matrix and fiber architecture, industrial applications, links between process, microstructure, material properties and structural performance.

Mechanical properties: linear elasticity of orthotropic (and anisotropic) materials, classical laminate theory (CLT), progressive damage and failure mechanisms, edge effects, humidity and temperature effects.

Homogenization: principles, mean-field homogenization applied to linear elasticity, extension to elastoplasticity, applications to short and continuous fiber-reinforced plastics.

Numerical simulation: finite element analysis. Design of composite marine structures: design rules and manufacturing constraints, parameterizations and optimization algorithms.

Learning outcomes

The students will be able to select the adequate composites material for the design of components for Ships and offshore structures, including Offshore wind turbines

Prerequisites

Title: **Fracture mechanics, damage and fatigue** **5 credits**

Ref: EMSHIP _M2-ULIEGE-xx
Ref: MECA0058-1

Prof: Ludovic Noels Teaching Period: sem. 3

Link: https://www.programmes.ULIEGE.be/cocoon/20222023/en/cours/MECA0058-1.html

Course contents

The class presents the basis of fracture mechanics. Failure of structures is explained by studying the physic of materials. This behavior is then modeled analytically. Finally numerical methods applied in fracture mechanics are presented.

Subjects covered by the lectures are:

- Linear elastic fracture mechanics (LEFM)
- Non-linear fracture mechanics (NLFM)
- Fatigue
- Design approaches
- Recent numerical approaches

Learning outcomes

Through a deep understanding of the theory and the realization of a project, the student will be able to apply numerical tools to design structures and study crack propagation problems. In particular:

- He/she will have a deep understanding of fracture mechanics theories and will be able to summary, compare and explain them.
- He/she will have a deep understanding of the resolution methods of fracture mechanics problems, and will be able to summary, compare and explain them. He will also know their application range.
- He/she will be able to apply the resolution methods to classical problems of fracture mechanics.
- He/she will be able to analyze and to evaluate (justify and criticise) these methods.
- He/she will be able to analyze new problems.

Prerequisites

Good knowledge in solid mechanics and basic knowledge in finite-element method.

Title: **Vibration testing and experimental modal analysis**	**5 credits**
Ref: EMSHIP _M2-ULIEGE-xx Ref: MECA0062-1 **Prof: Mathieu Bertha**	Teaching Period: sem. 3

Link: https://www.programmes.ULIEGE.be/cocoon/20222023/en/cours/MECA0062-1.html

Course contents

Vibration sensors: displacement, speed, acceleration. Signal analysis: power spectral density, discrete Fourier transform, FFT algorithm, digital spectrum analyzers, aliasing and leakage phenomena. Excitation methods in vibration: types of excitation signals (impact, sine sweep, pseudo-random, etc.), electrodynamic exciter, impulse hammer.

Theoretical background of modal analysis: transfer function, receptance, mobility, impedance, Bode diagram, Nyquist diagram, development of the dynamic influence coefficient matrix in terms of poles and residues. Identification methods: phase separation and phase resonance methods, identification of modal parameters on the basis of the frequency or impulse response functions, 1 DOF-method (peak picking, circle fitting) and multi-DOF methods, influence of residual terms, multiple excitation. Introduction to model updating methods in linear elastodynamics. Diagnosis of the mechanical state of a machine through vibratory measurements.

Learning outcomes

The aim of the course is to train students to use vibration measurement equipment in laboratories, to acquire, process and exploit the vibratory signals as well as modal identification methods, comparison techniques between theoretical and experimental results and parametric correction methods for structural models on the basis of experimental results.

Prerequisites

This course requires a basic knowledge in mechanical vibrations.